

Woven Thermal Protection System (WTPS) - a Novel Approach to Meet NASA's Most Demanding Missions



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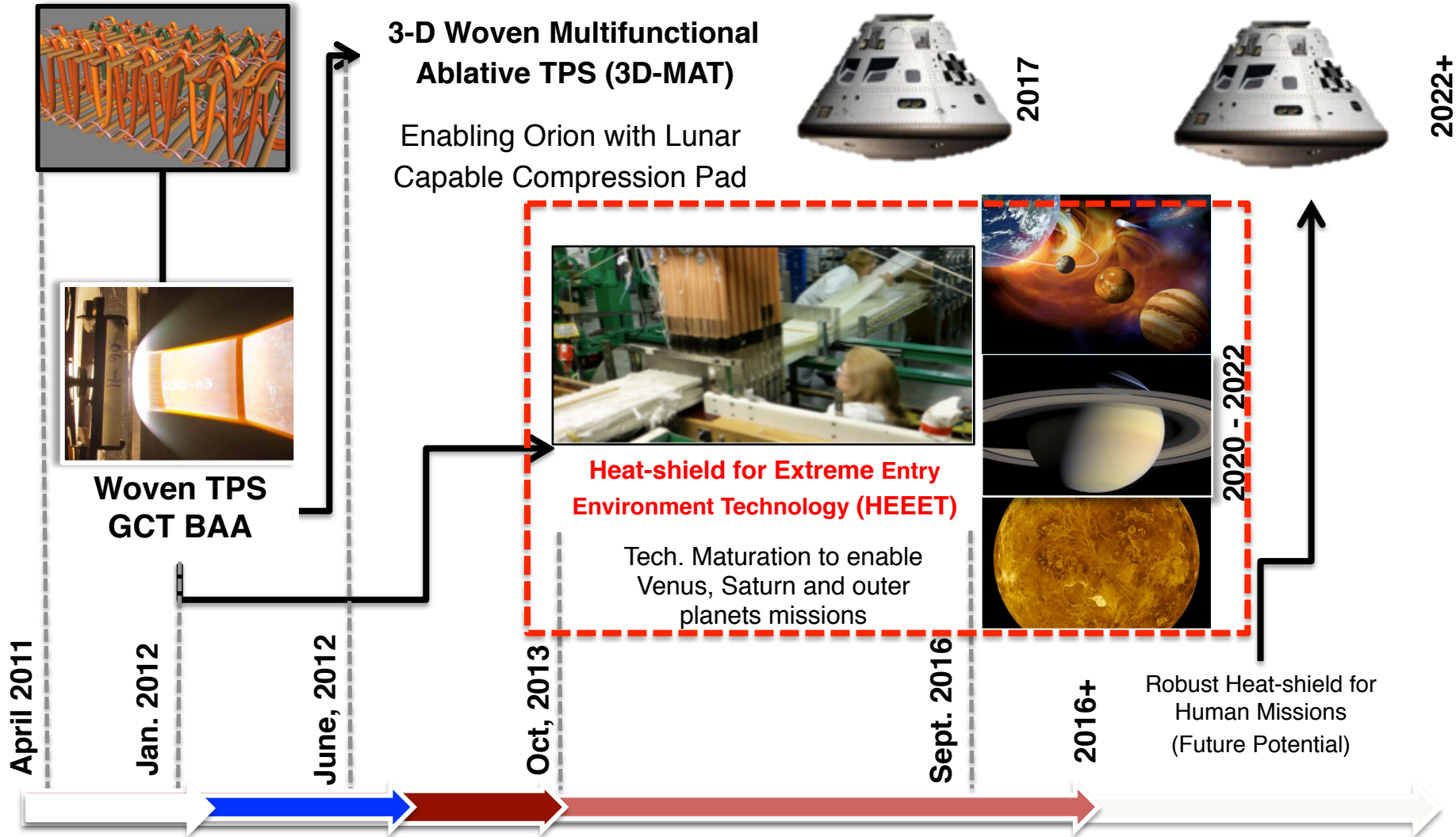
Outline



- **WTPS Evolution**
- **Intro. To HEEET Project**
- **Downselected HEEET Architecture**
- **Benefits of HEEET Architecture**
- **Aerothermal Testing Summary**
- **Heatshield Components and Technology Maturation Challenges**
- **Summary**



Evolution of Woven TPS



➤ NASA (STMD and SMD Mission Directorates) is committed to developing and providing HEET as a Government Furnished Equipment (GFE) for the upcoming Discovery proposers

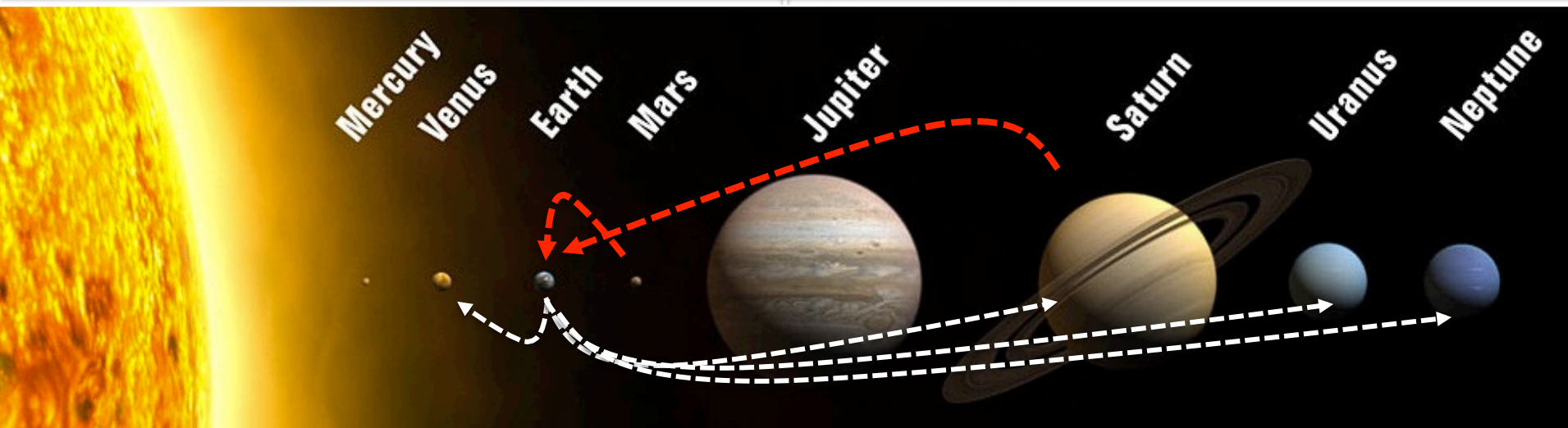


HEEET Background



- HEEET is an technology development project to advance 3-D woven resin infused TPS materials that can be tailored to SMD robotic missions ***without constraining the mission or limiting the science.***
- Recommended science missions include:
 - ◆ Venus probes and landers
 - ◆ Saturn and Uranus probes
 - ◆ High speed sample return missions

	OML Shape	Diameter	Nose Radius	TPS Thickness
Saturn	45° spherecone	~1m (40")	~7.0"	~2.5"
Venus	45° spherecone	~3.5 m (140")	~25"	~1.5"
Earth Sample Return	45° spherecone	~1m (40")	~7.0"	~1.5"

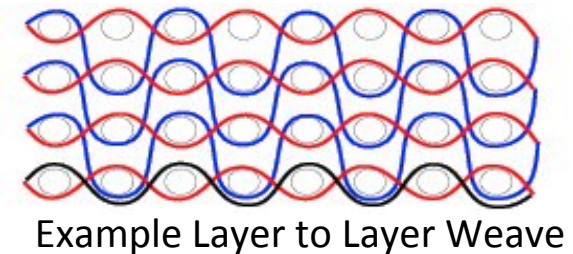
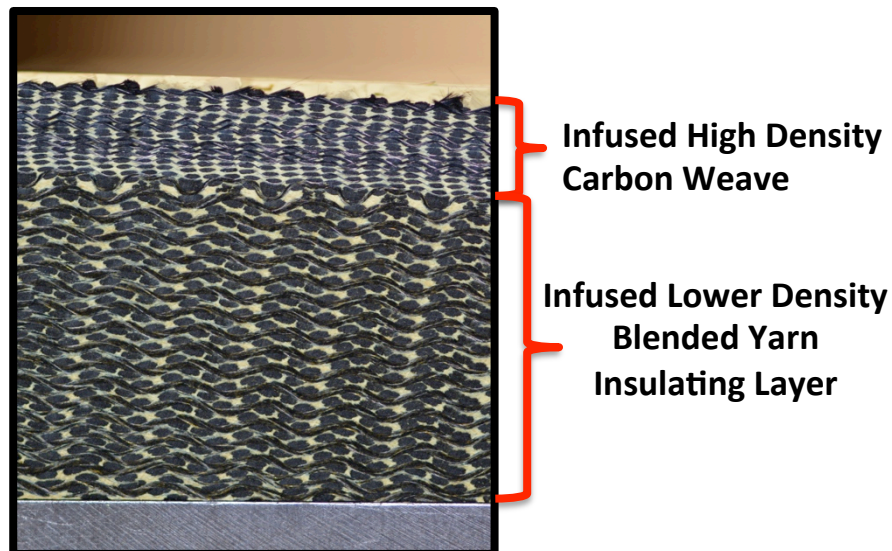
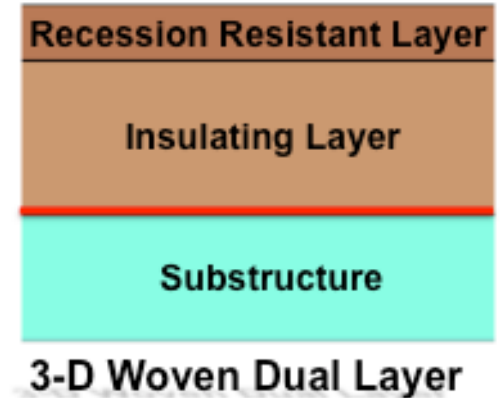




HEEET Material



- Recession and insulating layers are woven together in 3D
 - Mechanically interlocked (Z fibers)
- Weaving results in orthotropic material
 - Properties vary in Warp, Fill and Through-The-Thickness (TTT) (X,Y and Z)
- Single uniform resin infusion (vacuum assisted infusion)
- Weave architecture and resin infusion level downselected during HEEET Formulation (FY13)

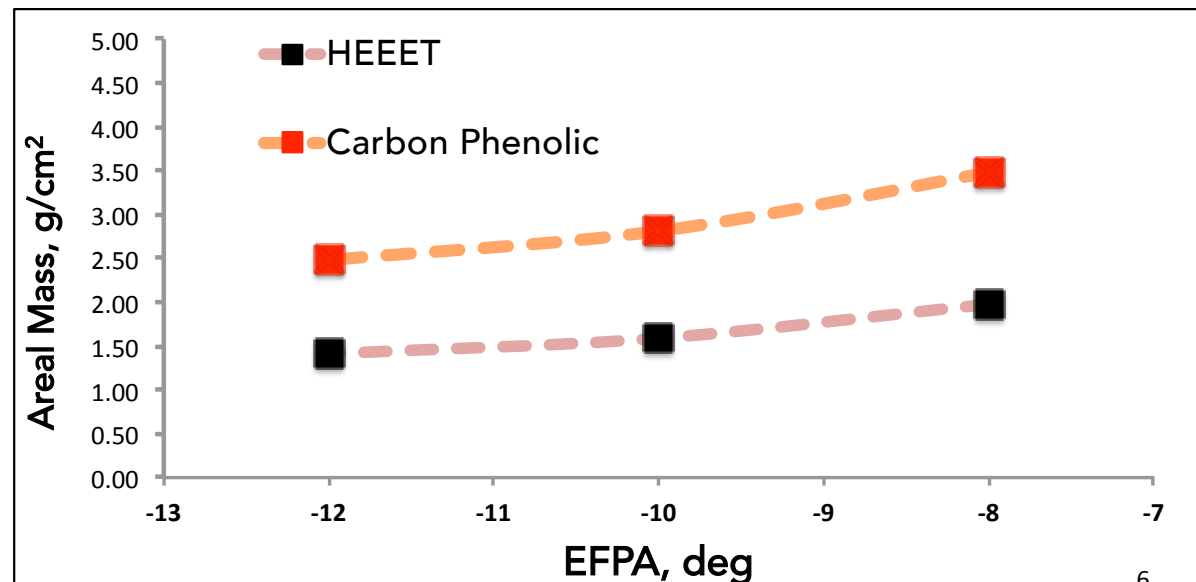


Benefits of HEEET Dual Layer Architecture



- Areal Mass Trade Studies Completed for:
 - ◆ Saturn Probes
 - ◆ Venus
 - ◆ Uranus small probes
 - ◆ Sample Return Missions
- All trades indicate substantial TPS mass savings over heritage carbon phenolic with zero margin sizing and using a preliminary HEEET response model

Sample Return Mission Trade Studies
($V = 15$ km/s, $M = 50$ kg, Dia. = 0.8 m) :
TPS Areal Mass and Thickness

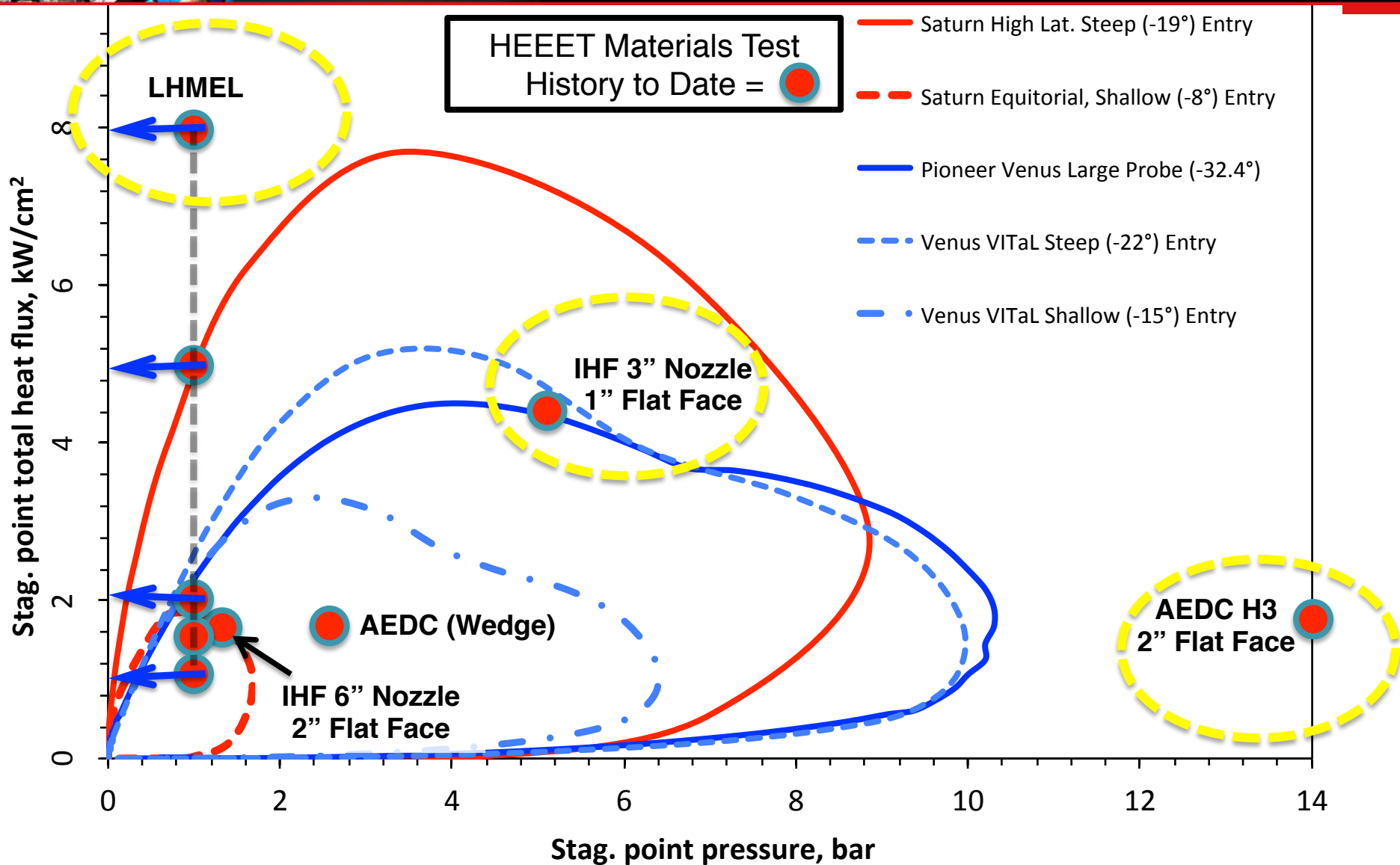


- 3-D WTPS allows larger entry corridor, robustness and mass efficiency
- Carbon Phenolic – mass inefficient especially at shallower EFPA
- Mass savings of ~40% over CP



Aerothermal Testing

Arcjet Design Space & HEEET Test History



Testing Approach



Test Coupon Design

- Drew upon heritage Pioneer Venus / Galileo test configurations to design test article geometries where applicable
- Utilized modern CFD capabilities to refine test article configurations, position within test facilities and estimate arc heater settings
- LHMEEL testing utilized heritage Carbon Phenolic test techniques used to qualify material for Shuttle solid rocket motors to test for failure modes

Facility Capability Enhancement

- IHF 3-inch nozzle design and fabrication was supported by NASA's SMD
- Model design and test support modifications for AEDC testing supported by AEDC/DoD

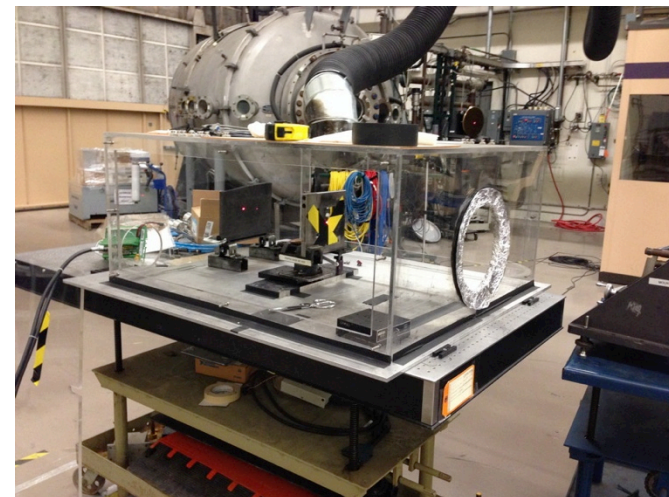
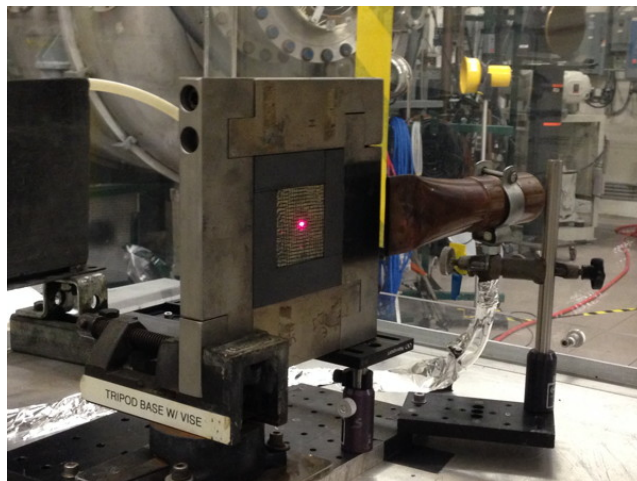
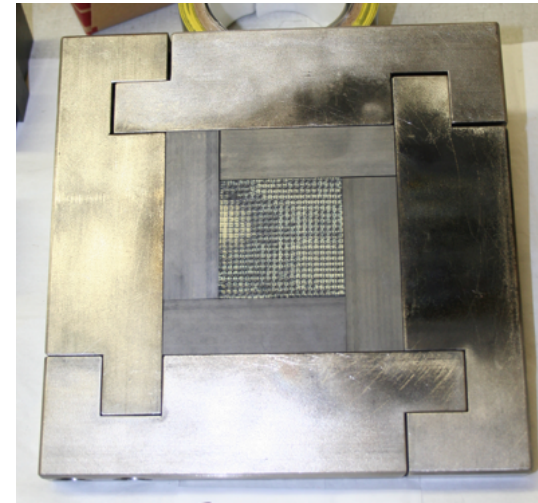
Baseline Material Tested for Comparison to HEEET

- Test articles included fully dense tape wrap and chop molded carbon phenolic

LHMEL: Failure Mode Testing



Model ID	Description	Density (g/cm ³)	Duration (sec)
HEEET 2	1000 W/cm ²	0.88	30
CMCP 3		1.45	30
TWCP 3		1.45	30
HEEET 6	2000 W/cm ²	0.88	15
CMCP 1		1.45	15
TWCP 1		1.45	15
HEEET 40	5000 W/cm ²	0.89	6-7
HEEET 20	8000 W/cm ²	0.89	5
CMCP 4		1.45	5
TWCP 4		1.45	5



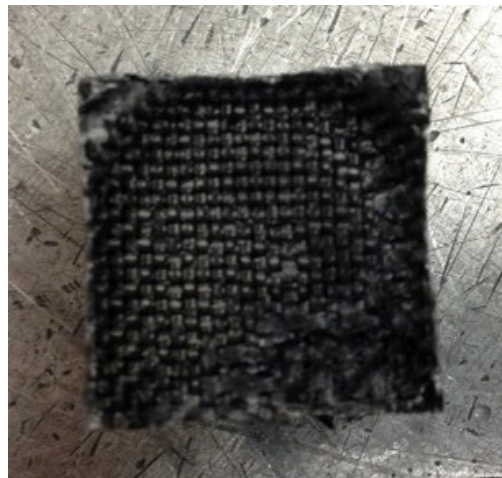
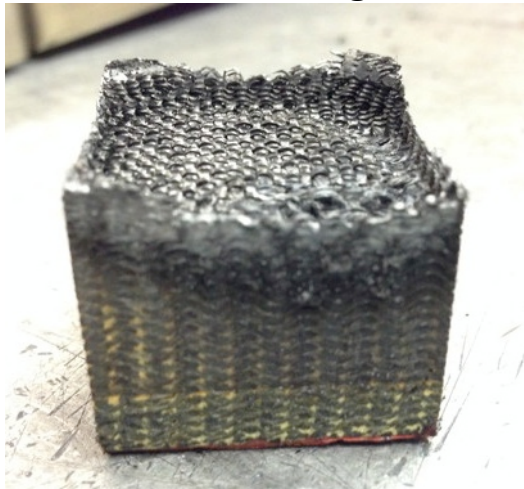


LHMEL: Failure Mode Testing

Post-Test: 8000 W/cm², 5 sec.

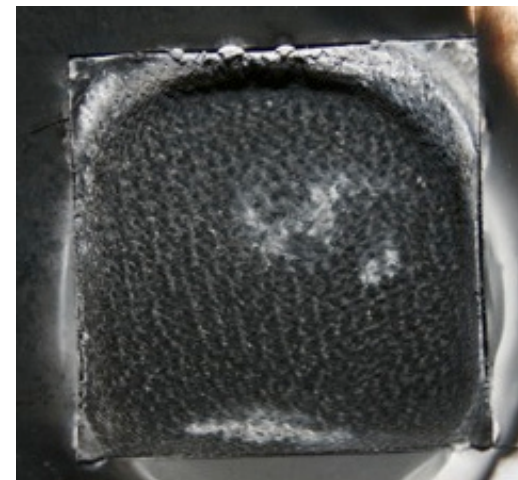
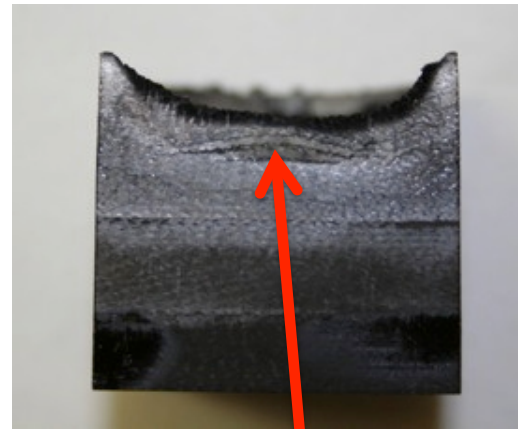


HEEET Acreage



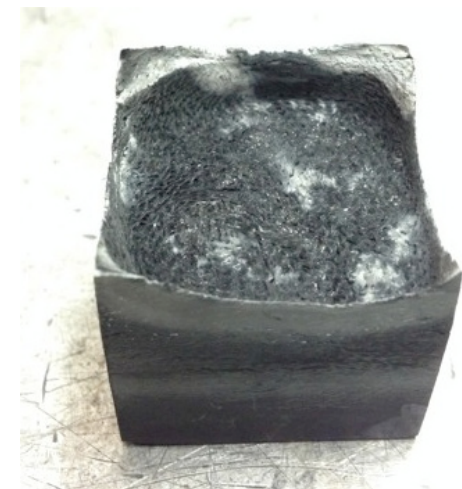
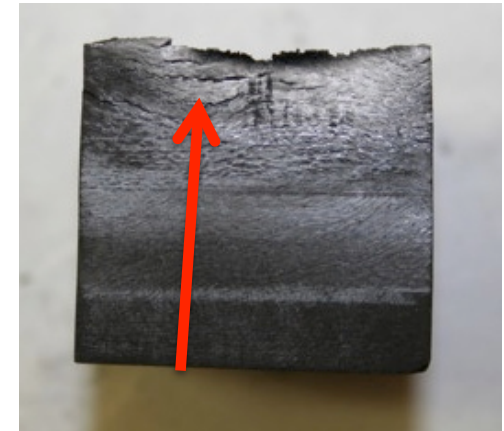
No surface spallation, delamination or cracks

Tape Wrap CP



Ply lift and sub-surface cracking

Chop Molded CP

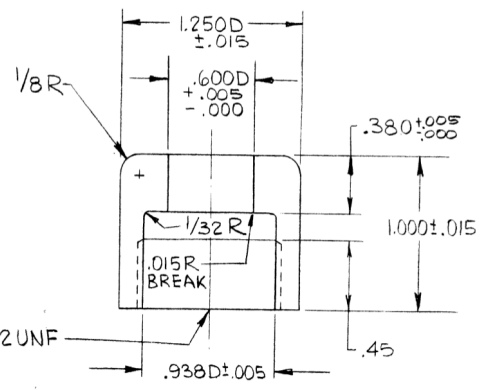


Ply lift and sub-surface cracking



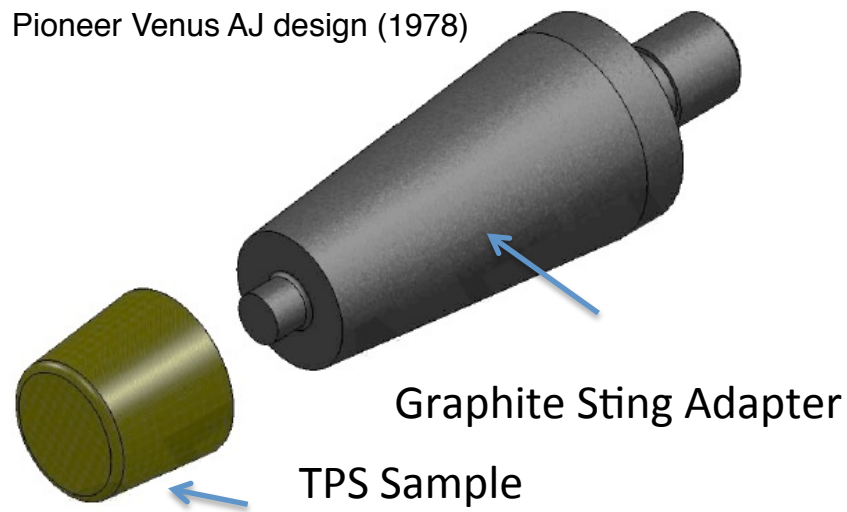
IHF 3" Nozzle 1" Flat Face Stagnation Acreage HEEET Stag. Heat-Flux $\sim 5000 \text{ W/cm}^2$ @ 5 atm

- 4 HEEET models tested
 - Exploratory test to confirm facility operability with new nozzle configuration

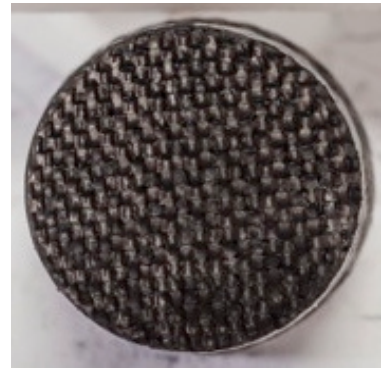


MAKE FROM CIRCUMFERENTIALLY-WRAPPED CARBON PHENOLIC TUBING.

Pioneer Venus AJ design (1978)



Pre-Test



Post-Test

- Failure mode test
- Uniform Recession observed for HEEET material

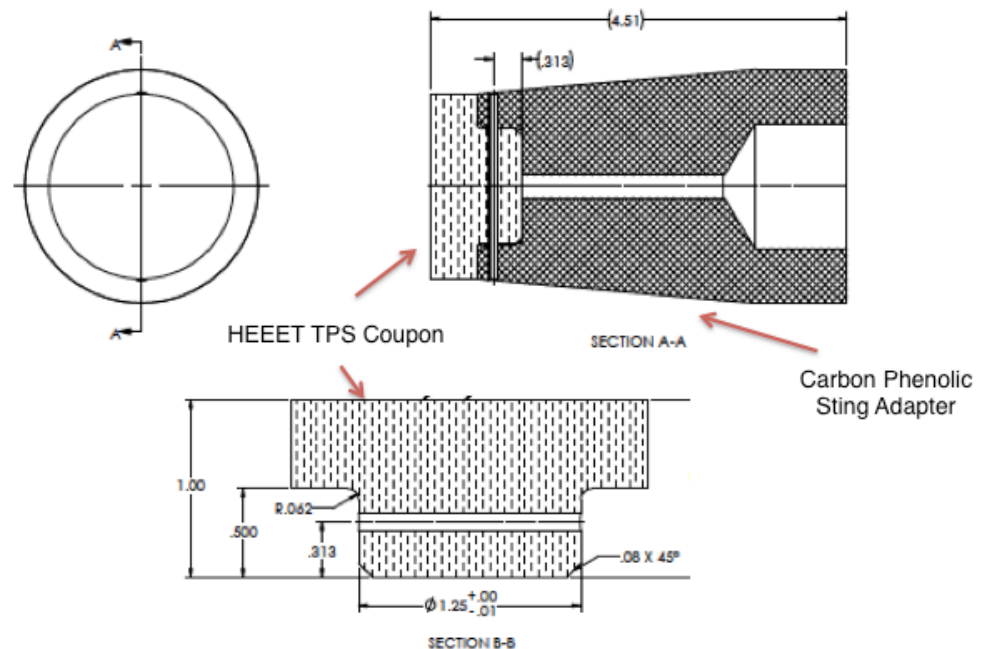


AEDC High Pressure Stagnation



- 6 HEEET and 1 Chop Molded Carbon Phenolic(CMCP) models tested
 - Exploratory test to confirm facility operability with stagnation configuration
- The targeted conditions for this test were 1850 W/cm^2 and a stagnation pressure of 14 atm
- Each sample was exposed for ~ 2 seconds
 - Test time limited to 2 sec for all of the HEEET tests as the high density top layer was ~ 0.2 " thick and the intent was not to burn through that layer into insulative sub-layer which is lower density

- Sample design
 - 2" diameter, 1" thick
 - Bonded & pinned to a carbon phenolic holder
 - No instrumentation (TC's)



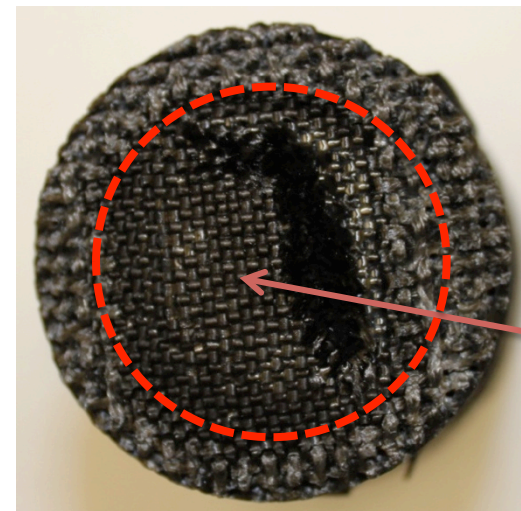
AEDC High Pressure Stagnation Acreage HEEET Stag. Heat-Flux $\sim 1850 \text{ W/cm}^2$ @ 14 atm



Pre-Test



Post-Test

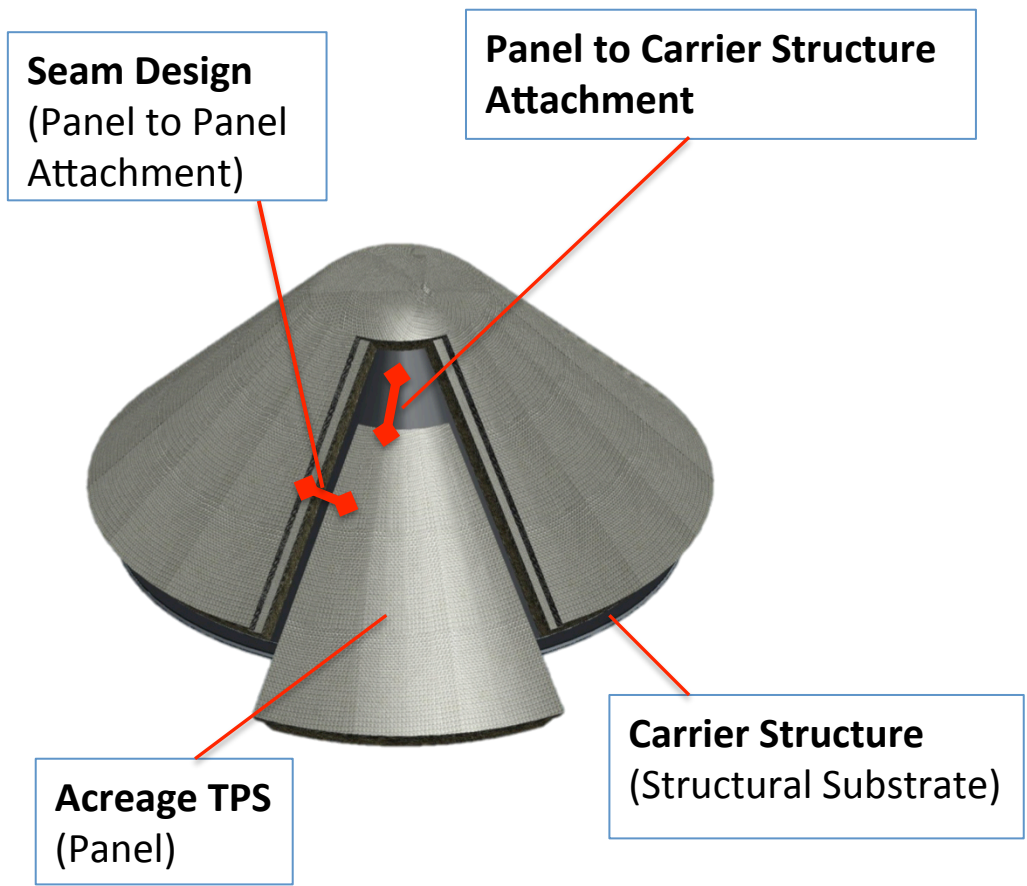


Recession
Layer

The recession was uniform. Post test picture captures some tows (frayed and charred fibers visible). This happened when exiting the flow when there was significant shear forces on the model.



HEEET Heatshield Components



- 4 Basic Heatshield Components
 - **Acreege Material**
 - Seam Design/Material
 - Panel to Carrier Structure Attachment
 - Carrier Structure
- Building and Testing of 1.2m Prototype (engineering test unit) is culmination of Manufacturing, AI&P (assemble, integration and production) and Design/Analysis activities

- 45° Sphere cone assumed for Venus and Saturn
- Nose is separate molded part



Technology Maturation Challenges



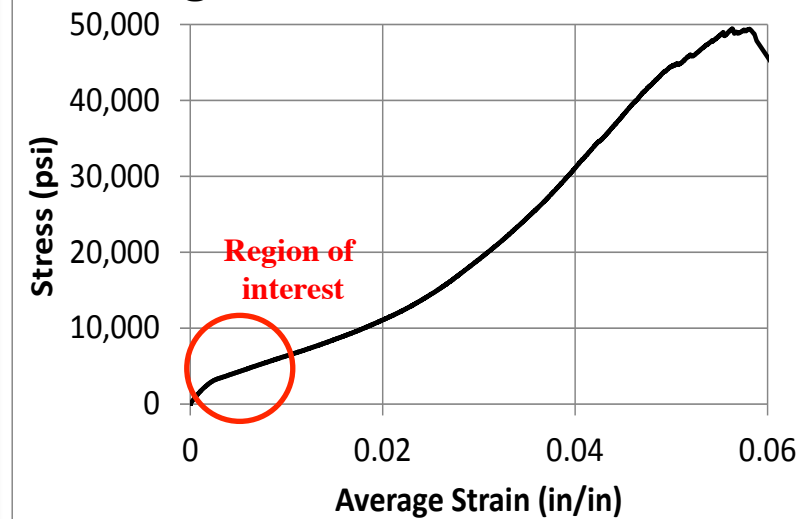
- System/Manufacturing
 - Seam Design
 - Forming gores and nose
 - Resin Infusion at scale
- Integration
 - Aeroshell sub-structure
 - back shell
- Flight System design tools development and verification
 - Thermal response an example of design tool needed
 - Arc jet testing at relevant scales
 - Prototype Test Unit



Seam Design

- Seam selection is an interplay between manufacturing, AI&P, and aerothermal/structural performance
- Initial stress work will focus on seam and bondline failure as they are the weakest aspect of the design

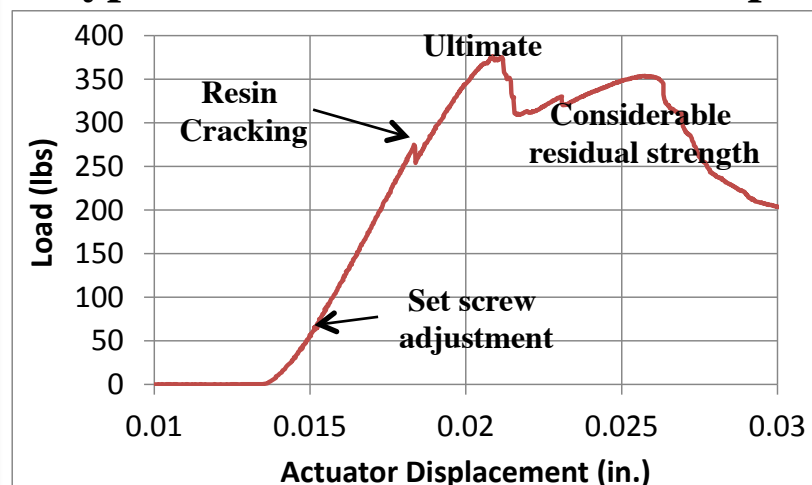
Acreage Material Stress vs Strain



IHF 6" Nozzle Testing Preliminary Joint Concepts



Typical Result for Seam with Strap



Summary



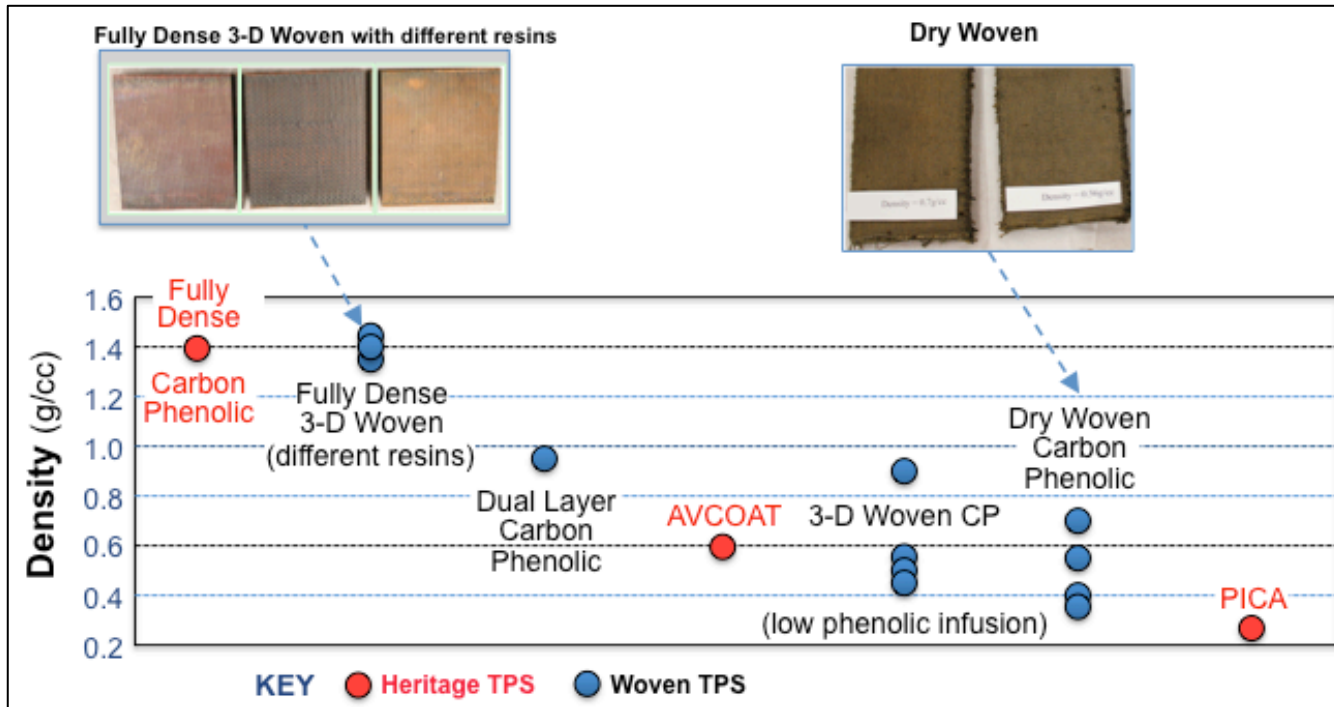
- HEEET woven material options are viable alternatives to heritage carbon phenolic
- Facility upgrades have widened the envelope for ground-based testing capabilities allowing more extreme conditions to be tested
- HEEET team is committed to delivering a mature technology by 2017
 - Successful formulation activities (testing, system studies and planning) and community advocacy has resulted in mission infusion opportunities for upcoming Discovery and New Frontier Missions
 - Team is working challenges in maturing the technology and on-going studies and progress will be reported to the community

Acknowledgements



- This work was performed under the STMD/GCDP funded Heatshield for Extreme Entry Environment (HEEET) Program
- SMD – PSD is acknowledged for supporting the HEEET formulation activity and funding the 3-in nozzle upgrade
- The HEEET team is very grateful to the staff at AEDC , NASA Ames and LHMEEL for excellent test support
- This work is supported by personnel at multiple NASA centers (ARC, LaRC and JSC)
- We also acknowledge our industrial partner Bally Ribbon Mills

Large Application Space Possible



- Many ablative TPS options possible and have been manufactured
 - Dry-woven to fully resin infused systems
 - Density ranging from 0.3 g/cc – 1.4 g/cc
- Current HEEET activity has downselected to a dual layer system to meet specific mission needs for extreme entry (Venus, Saturn, outer planets, sample return)
 - Depending on mission needs many other options are possible